High-Hardness, Highly Ductile Ferrous Articles

Technical Field

Steel and other ferrous articles are austenitized, then held at a temperature to convert at least 60% to bainite, then immersed at ambient temperature to convert the remaining 40% or less to martensite; the articles are then cold worked to achieve excellent serviceability.

Background of the Invention

The effects of seemingly infinite variations of temperature treatment on steel and other ferrous articles have been studied and utilized for decades, but there remains a need for continuous improvement in hardness, tensile strength, ductility, and fatigue life. Some types of steel articles – those which are constantly or frequently stressed -- could particularly benefit from improvements in all four properties.

Rice, in US Patent 4,225,365, introduces the subject of austempering as follows (column 1, lines 53-64):

> "U.S. Pat. No. 1,924,099 issued to E. C. Bain et al on Aug. 29, 1933 describes a process known as austempering. Such process involves the steps of: (a) heating a steel article above an upper critical temperature to assure a change in the morphology of the article to substantially 100% austenite; (b) quenching the article

below approximately 540°C (1000°F), but above the temperature of martensite formation or the so-called martensite start (M_s) line; and (c) holding the steel article at such an intermediate temperature for a preselected period of time sufficient to convert the morphology of the article to form other than 100% martensite."

The Rice patent goes on to state that it is "imperative to transform the austenite microstructure of the bar or similar article directly to a lower bainite microstructure by choosing a preselected cooling rate ...." (col. 6, lines 42-45). Austempering is practiced on pins, washers and fasteners by Olivera et al in US Patents 6,171,042 and 6,203,442 – see col. 3, line 30 and col. 6 line 32 of the '442 patent.

Other prior art patents discussing the desirability of converting austenite to bainite include Nakamura 4,470,854 and especially Faust et al in US Patent 5,868,047, who describe improved insert bits for use with a powered screwdriver. Faust et al say, in column 1, lines 30-40:

> "It is known to austemper bits of tool steel to improve resistance to fatigue. Austempering produces bits having a microstructure of bainite. The insert bits are heated to a temperature above 723°C so that the steel is first austenitized. Then, the steel is cooled to a temperature above the martensite start temperature, for example, around 300°C, and held at that temperature for a desired time to permit the transformation to bainite. No tempering is required. Austempering helps to reduce distortion or cracking during cooling and produces a tool having improved toughness, when

compared to tempered martensite at the same Rockwell C hardness("HRC")."

A time/temperature sequence is closely controlled by Amateau et al in US Patent 5,656,106. Tipton et al, in US Patent 5,910,223, using a procedure similar to Faust's description above, also aim to produce a bainite structure in articles already fabricated. Still other workers in the art have focused on the formation of martensite after austenitizing – see Celliti et al US Patent 4,373,973.

Pfaffmann, in US Patent 4,637,844, recognizes that austenitized portions of an article may be entirely or mostly transformed to bainite, with the remainder being martensite. Koo et al, in US Patent 5,900,075, obtain "predominantly granular bainitic and martensitic microstructure," depending on the elements of the particular alloys. Arnett et al, in US Patent 6,080,247, rely on working to obtain an austenite/martensite microstructure in their subject articles.

Cold plastic deformation is used to form an article after a bainite microstructure is imparted to a hot rolled product, as described by Pichard in US Patent 5,919,415.

The various studies and improvements described in the patent literature and elsewhere still do not achieve the most desirable combinations of properties for articles subject to repeated stress over long periods of time.

Summary of the Invention

We have developed a process for the conditioning of ferrous, particularly steel, articles and parts that achieves significant improvements in tensile strength, hardness, ductility and fatigue life. We are most interested in improving the properties of chain parts, which are subject to repeated stress, and all four of these properties contribute to their usefulness and longevity. We refer to these properties together as serviceability.

Our process is applicable to any ferrous article; that is, it may be practiced on cast or ductile iron articles as well as steel articles formed by casting, molding, stamping, fabricating, shaping from wire, bar, or other stock, or formed in any other conventional manner. The type of ferrous composition used for forming the article – for example, the type of steel – should be considered in the practitioner's choice of time/temperature treatments.

In our process, a ferrous article is austenitized, then transferred and held at a temperature to convert at least 60% to a bainite microstructure, then immersed in a thermal bath at ambient temperature to convert the remaining 40% or less to martensite; the articles are then cold worked to achieve excellent servicability.

Brief Description of the Drawings

Figure 1 is an isothermal transformation diagram for heat treating a steel article according to our invention, showing the target microstructure area.

Figure 2 is an illustration of a silent chain link and pin used to demonstrate the invention.

Figure 3 is a diagrammatic illustration of a preferred method of applying tensile deformation to a silent chain.

Figure 4 presents load and elongation data, in graphical form, to compare the energy adsorption of conventionally manufactured chain links and chain links of the invention.

Detailed Description of the Invention

Throughout, our use of certain terms is intended to have the following meanings:

Thermal Bath: A liquid, typically an oil or molten salt, held at a predetermined temperature or within a predetermined temperature range, in which the article to be treated is immersed. Broadly, a furnace or other holding vessel may be used.

Compression Deformation: A permanent change in shape of an article imparted by impacting, burnishing, rolling, or other means of compressing the article, including shot peening.

Tensile Deformation: A permanent change in shape of an article imparted by stretching, i.e. applying a tensile force.

Plastic Deformation: Collectively, compression deformation and tensile deformation.

Cold Working: Manipulating or stressing to achieve plastic deformation.

Austenize or Austenitizing: Heating and cooling procedure with time/temperature regimen to achieve a substantially complete austenite microstructure in a ferrous article. The precise limits of time and temperature will vary with the metallurgy of the article, as is known in the art.

Serviceability: We use this term to mean collectively superior tensile strength, hardness, ductility and fatigue life.

Our invention includes a method of making a ferrous article of high serviceability comprising (a) forming the ferrous article (b) austenitizing the ferrous article at temperatures between 1450-1750°F (c) transferring the ferrous article to a thermal bath in a period less than 60 seconds (d) holding the ferrous article in the thermal bath at above the M_S temperature for a period from 10 minutes to three hours whereby the ferrous article comprises at least 60% bainite (e) quenching the ferrous article in a bath at ambient temperature to convert substantially all of the remaining austenite to martensite, and (f) plastically deforming the article to at least 60% of its yield strength. The article will have a hardness of R_C to R_C 63 or higher and excellent fatigue life.

While step c should be accomplished within 60 seconds, and preferably within 20 seconds, longer periods of time may be used so long as the article is kept at a temperature of at least 1450°F. We call this quickly transferring the article.

Our invention is applicable to articles made from a wide variety of steel and other ferrous materials. For chain links and many other articles, the steel will preferably have sufficient hardenability to obtain martensite or bainite. The article may be formed (step a) in any conventional or desired manner. The austenitizing step (b) is also conventional – typically the article is held in a thermal bath or furnace for a time sufficient to convert to 100% austenite, then quickly transferred to the thermal bath for step (d). The temperature and time parameters of step (d) may vary with the metallurgy of the article, but in any case it is necessary to convert at least 60% of the austenite to bainite; the temperature may vary somewhat, as will be illustrated with respect to Figure 1, but should not be allowed to approach the M_S temperature to within less than 20 degrees Fahrenheit. The length of the quenching step (e) may also vary with the type of ferrous material, but should result in conversion of substantially all of the remaining austenite to martensite. The plastic deformation step (f) will be further explained below.

The outline of **Figure 1** is a dimensionless, but otherwise more or less conventional, plot of time and temperature for isothermal transformation of ferrous materials as in step (d) above. Line 30

represents the beginning of transformation, line 32 is 50% transformation, and line 31 is 100% transformation, as is known in the art. Horizontal line M_S is the martensite start line; the lower bainitic zone is above it, as is known. Our invention aims to place the article, at the end of step (d), within the shaded area ABCD. Generally, regardless of the composition of the ferrous article, this means holding the article in a furnace, thermal bath or otherwise holding it at a temperature from 20 degrees Fahrenheit above the M_S for a period of ten minutes to three hours. For most steels, and for the low carbon steel we use for chain links, a modest temperature range more than 20 degrees above the M_S temperature will suffice, (for example, up to 500°F over the M_S), but with some steels temperatures as high as 1050°F may be used.

While our invention is applicable to articles made from a wide variety of steel and other ferrous materials, it will be illustrated with respect particularly to chain links made of steel having a carbon content of 0.2 to 1%. The chain links are generally flat, saddle-shaped units having two holes for pins, as illustrated in **Figure 2**. A single chain link is a simple unit having two holes 1 and 2 for pins 3 which connect the links in a series. To form a chain, pins 3 may pass through a plurality of parallel links.

Our invention includes, as a part of step (f), a compression deformation step. Individual articles, for example chain links, are subject to compressive stress at -50,000psi to -200,000psi. This may

be accomplished by shot peening using various masses and hardness of the shot, angles of impingement, quantities, and velocities, and duration of the treatment, with or without accompanying manipulation of the workpiece.

Referring now to **Figure 3**, it should be understood that step (f) includes both compression deformation and tension deformation. The illustration in Figure 3 is one of two preferred methods for tension deformation. Chain 10 is placed on sprockets 11 and 12. In this illustration, sprocket 11 is held stationary or is able to turn while offering resistance, and a measured force is applied to turn sprocket 12. Segment 13 of chain 10 is therefore stretched and segment 14 is under no tension. Various segments of the chain may be treated in the same manner simply by rotating the sprocket and applying tension to them. Where both sprockets turn, the procedure is called dynamic stress. Alternatively, in a static method, neither sprocket 11 nor sprocket 12 is turned; rather, tension is applied by slightly increasing the distance between the sprockets under a measured force on one or the other, or both, of the sprockets, thus tensioning segments 13 and 14 at the same time. By either method, the chain is said to be prestressed, meaning that the systematic stressing is part of the manufacturing process; the applied stress is generally greater than would be expected in use. Sprockets 11 and 12 may be replaced by rolls, particularly in the second described method. Our invention includes such prestressing, by tensile deformation, of chains of links made by the process described herein, as a final deformation step.

The prestressing should be carried out to at least 60% of yield strength, and may range from 60% of yield strength to 97% of yield strength. Yield strength may be determined by testing similar chains to failure.

Figure 4 presents load and elongation data, in graphical form, to compare the energy adsorption of conventionally manufactured chain links and chain links of the invention. Elongation is plotted against load. The object of the study was to determine the improved properties of individual chain links made by our process. It will be seen from the diagram that the chain links of the invention, represented by line 21, can be elongated well beyond the conventional link, and are permanently elongated by, for these specific links, 0.05 inch. Note that our invention link at R_C56 is capable of elongating to at least 0.080 inch compared to a softer R_C50 link of conventional quench and temper which failed at 0.068 inch. The ability of our invention link at R_C56 to absorb more energy without failing than conventional (R_C50) is evident in the hysteresis curve, i.e. the dashed return portion of line 21.

A comparison was made of three different types of chain links. Chain links of conventional quench and temper sequences, even though subjected to both compressive and tensile deformation, failed, on average, after 28,304 cycles. Chain links of the bainitic structure as imparted by the above recited time-temperature parameters of the invention followed by only the tensile deformation failed, on average,

after 93,073 cycles. Chain links of the bainitic structure as imparted by the invention's above recited time-temperature parameters followed by both compression deformation and tension deformation failed after 261,628 cycles, on average, demonstrating a greatly improved fatigue life. By a "cycle" as used in this comparison, we mean alternating the application of a relatively high and a relatively low force; generally the same forces are used in all cycles.

Our invention is not limited to the treatment of chain links, but may also be applied to numerous different kinds of steel and iron articles, such as washers, screws, screwdriver bits, masonry nails, bolts, fasteners, springs and many other articles and parts of machines likely to be subjected to serviceability challenges. In addition to chain links, we particularly apply the invention to chain pins, sprockets, and tensioner arms. Because a chain link has two pin holes which are the focus of stress and wear in use, the plastic deformation described with respect to Figure 2 is particularly suited for it. In the case of a sprocket, plastic deformation is practiced by tooth or form rolling. Other shapes of articles may demand other methods of plastic deformation. In each case, however, we apply a stress to the point of at least 60% of yield strength.